enough size, many of these species populations will remain permanently isolated and thus subject to inbreeding, continued decline in numbers, and eventual elimination from that patch of habitat.

Aquatic ecosystems are also subject to isolation. All of Wisconsin's large rivers, most of its medium-sized rivers, and many smaller streams have been fragmented by dams. Fragmentation causes streams to become a series of modified ecosystems which no longer represent the native ecosystem in structure, function, and composition. Lake shores have also been fragmented by sand blankets and vegetation removal associated with shoreline developments. Dams prevent fish from reaching upstream spawning grounds, but there are other, more subtle effects of dams. For example, damming frequently isolates mollusks from the fish that host their larval stages; mollusks unable to complete their life cycle because of this isolation are eventually eliminated from the stream. For other species, populations are diminished when individuals succumb to siltation and other effects of damming.

Edge Effects

Edge effects occur near the interface of two or more different habitat types. Edge effects are beneficial for many plant and animal species, since edge allows them to take advantage of two or more habitat types for their survival. However, many other species are negatively affected by too much edge. The concentration of many species near edges causes increased competition, predation, and parasitism. For example, waterfowl nesting near the edges of grassy fields experience high nest predation, as do some songbirds nesting near forest-field edges. Or, some plants may disappear from previously suitable interior habitat when a new edge changes the micro-climate. As community or ecosystem islands get smaller or more disturbed, they become less and less viable for interior plants and animals. In effect they become all edge.

Encroachment of exotic species is closely associated with edge dynamics. In forests, many exotics gain entry to interiors by first getting established in the disturbance zone associated with human-caused disruption. Interior edge, which is more common in the north, is caused by logging, agriculture, blowdowns from wind storms, fire, and residential and commercial development, and takes on the same form and effect as exterior edge. Area- and edge-sensitive interior species are especially vulnerable to interior edge conditions.

Corridors for roads, power transmission lines, and pipelines create linear edge throughout the north, while in the south, these corridors sometimes bisect woodlots, wetlands, and grasslands. These corridors are havens for edge species and allow for penetration of species into otherwise continuous communities and ecosystems.

Environmental Pollution

Environmental pollution is the human-induced addition of many types of substances to air, land, and water in quantities and/or at rates that harm organisms, habitats, communities, ecosystems, or human health. Examples are nutrients, heavy metals, organic compounds, and sediments. Pollution may change the physical, chemical, or biological characteristics of air, water, or land, thus affecting the health, survival, or activities of living organisms in a variety of detrimental ways, including impacts on genetic, species, community, and ecosystem diversity.

Pollution may change the physical, chemical, or biological characteristics of air, water, or land—affecting the health, survival, or activities of organisms and contributing to the forces that simplify and fragment communities and ecosystems.

Any Department policies relating to biological diversity need to consider the effects of pollution and the efforts required to manage resources that have been adversely affected by pollution. The following examples illustrate some of these effects as they relate to water, air, and land resources.

Adverse Impacts to Surface and Ground Water Systems

Poorly managed construction sites and bare fields allow soil to wash off the land in runoff. This sediment can smother gravel riffles in a stream, destroying the habitat for aquatic invertebrates and spawning sites for some fish. Excessive organic waste flowing into a lake or stream uses up dissolved oxygen as it decays, which can kill aquatic life either through direct toxicity, destruction of habitat or food supplies, or by elimination of the dissolved oxygen needed by aquatic plants and animals. Phosphorus and other nutrients flowing off fertilized lawns and cropland into waterways may allow growth of excess algae and other aquatic plants. When large amounts of this vegetation die, decomposing bacteria use up dissolved oxygen, killing fish and other aquatic life.

Direct discharge of industrial effluent and sewage, which contain organic residues, chemicals, and sediments, can limit dissolved oxygen in the receiving water, otherwise change water chemistry, alter habitat, and kill organisms. Some chemicals present in industrial and municipal effluent, such as dioxin, have been shown to cause diseases, suppress the immune systems of a variety of species, harm reproductive capability, and produce genetic defects in offspring. The temperature of wastewater may also change normal aquatic temperature gradients and disrupt the life cycles of some aquatic plants and animals.

Pollution of ground water, caused by events such as gasoline leaking from underground storage tanks, nutrients leaching from inadequate septic systems, or pesticides washing off farm fields, poses a direct human health hazard when it reaches household water supplies. Contaminated ground water can also flow into streams and lakes, creating the same pollution effects as effluent that has directly entered surface water.

Adverse Impacts from Air-Carried Pollutants

There is increasing evidence that chronic exposure to certain levels of air pollution impedes the long-term survival and vigor of many species of plants. Trees in heavily polluted urban areas, for example, have a much shorter life span than trees of the same species in less polluted areas. In fact, some species of trees simply cannot grow in areas with severe air pollution. For example, high levels of ozone in the air of southeastern Wisconsin are known to limit the growth of several species of trees. Even at moderate levels of air pollution, some individuals within a population are genetically more sensitive to air pollution and will be eliminated from the population, resulting in simplification of the gene pool. This is a good example of reduction in genetic diversity. Neither the short-term nor the long-term implications of this simplification is understood at this time.

Acid deposition from air-carried pollutants may change water chemistry in some lakes, which in turn can change the diversity and abundance of aquatic organisms and communities. Acid deposition may change the pH of a waterbody, which can encourage the release of mercury already present in sediments or substrates. This process may enhance bioaccumulation of mercury, which accumulates in organisms at the top of the aquatic food chain, affecting their health, survival, or offspring.

There is limited but increasing evidence that mammals, birds, and other organisms are also adversely affected by inhaling airborne pollutants such as pesticides, heavy metals, and organic chemicals. If not directly toxic within an adult organism's life span, these substances may be toxic to an organism's progeny by causing birth defects, depressing the immune system, or changing the structure of DNA.

On a global scale, a build-up of carbon dioxide in the atmosphere from fossil fuel combustion may eventually affect climate and dramatically change ecosystems by causing global warming. Also, the release of chlorofluorocarbons and similar chemicals also depletes the ozone layer in the earth's stratosphere, thus exposing living things to harmful levels of ultraviolet radiation with potentially dangerous global implications.

Adverse Impacts to Land-Based Systems

Many land-based activities fragment or simplify ecosystems through pollution, either by direct effects such as an oil spill or through secondary impacts such as soil erosion from poor farming practices. Spills of hazardous materials can affect local areas by smothering animals or interfering with their movement. Improper disposal of hazardous wastes can result in local concentrations of metals or organic compounds that harm organisms and ecosystems. Pesticides and herbicides can kill nontarget species, changing the species composition in the area and weakening the ecosystems in which these organisms lived.

Land-based pollution also impacts other systems, most often surface and ground water systems. For example, an improperly functioning landfill may contaminate nearby soil and harm plants and animals living in the immediate area. However, leachate from the same landfill may also enter the ground water and contaminate lakes and streams miles away.

Implications of Ecological Issues

Our current understanding of ecosystems and, specifically, the implications of ecological simplification, fragmentation, and pollution present considerable opportunities and challenges to the Department's management programs. Present-day management strategies consider biological diversity mostly in a peripheral sense. Although awareness is increasing, overall program planning is not consistently based on the principles of ecosystem management. It is these principles that will allow us to address biodiversity within the context of ecological, socio-economic, and institutional concerns. These principles and their application to Department programs are fully discussed in the next section, "Addressing Biodiversity through Ecosystem Management."

While the main implication of the ecological issues is the need to implement ecosystem management, there are a number of related implications that are important to identify. First, staff will need the tools to determine the appropriate spatial and temporal scales as they plan and conduct their management activities. In the past, we have been most comfortable managing individual DNR properties on a short time frame (ten years or less), a scale at which we are able to observe immediate and obvious impacts, obtain the most information, and provide the most certainty. In the future, we will be managing at a larger scale, considering entire landscapes and much longer time frames, with less obvious immediate impacts.

One important tool that will help us think and plan on the landscape scale will be the delineation of *ecoregions*. Ecoregions are large areas of the state that exhibit similar patterns in potential natural communities, soils, hydrologic conditions, landforms, lithology, climate, and natural processes. Ecoregions provide a focus for resource assessment and inventory of biotic and abiotic elements. We need to determine the most useful boundaries for ecoregions within the state, and develop goals and management strategies for them. These will give us the framework needed to choose our priorities and focus our resources on carefully selected programs and projects.

We will also need data management techniques such as computerized *Geographic Information Systems* (*GIS*) to compile information on ecosystems and landscapes and to design process-oriented management approaches. These and other tools, such as a statewide aquatic and terrestrial inventory, will help us collect and manage the extensive amount of information needed to make decisions at a landscape scale.

The issues of ecological simplification, fragmentation, and pollution are not distinct issues that can be debated or weighed in isolation from each other. Like ecosystems themselves, these issues are often interrelated and complex. Ecosystem management focuses on evaluating the cumulative impact of proposed actions at the landscape level. At the same time, fragmentation and simplification may not always be bad. For example, the creation of